Conventional Alignment Now and in the Future

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Presentation Outline

- Surface Network
- Transfer between Surface and Tunnel Networks
- Tunnel Network
- Components Alignment

Alignment Strategies

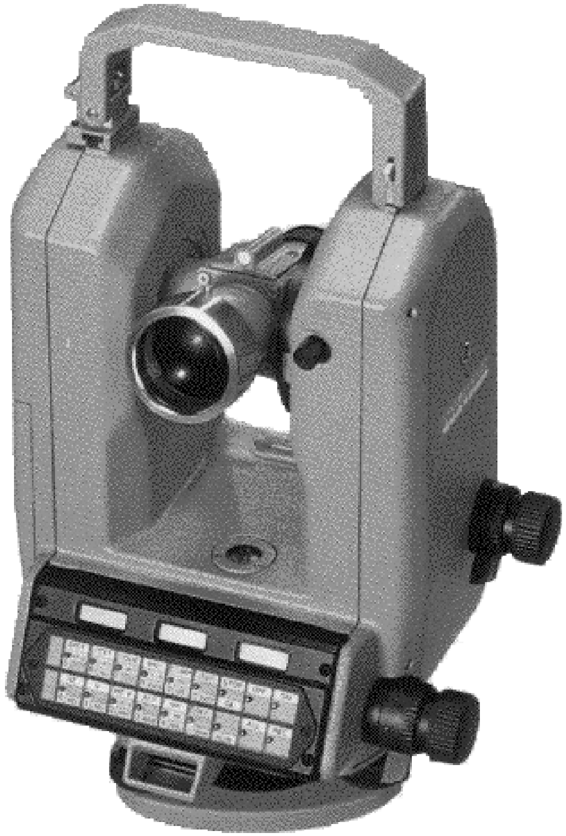
- Conventional Alignment
- Special Alignment Systems
  - Wire Systems
  - Hydrostatic Level Systems
  - Straightness Measurement Systems
- Beam Based Alignment

Conventional Alignment

Equipment

Typical Equipment and its Resolution

Theodolite	.3”
Gyro-Theod.	1”
EDM	100μm/.1km
GPS	4mm/30km
Level	.2mm/km
Plummet	.1mm/100m
L.Tracker	15μm/10m



Conventional Alignment
Surface Network

Purpose:

Establishing a global network of pillars and benchmarks to control the positioning, orientation and scale of the entire accelerator.

Instruments Used:

- Theodolites + EDMs + Levels
- GPS + Levels

GPS Geodetic Receivers

Trimble 4000 SSi model

Manufacturers

Allen Osborne Ass.

Ashtech

Dassault Sercel NP

Geotronics

Leica

Magellan

Novatel

Topcon S.A.R.L.

Trimble

GPS Research Software

BAHN/GPSOBS	European Space Agency (ESA)
Bernese Software	Astronomische Instituts Universität Bern (AIUB), Switzerland
CGPS22	Geological Survey of Canada, (GSC), Canada
DIROP	University of New Brunswick (UNB), Canada
EPOS.P.V3	GeoForschungsZentrum (GFZ), Germany
GAMIT/GLOBK	Massachusetts Institute of Technology (MIT), USA
GAS	University of Nottingham, Great Britain
GEODYN	Goddard Space Flight Center (NASA/GSFC), USA
GEOSAT	Norwegian Defense Research Establishment (NDRE), Norway
GIPSY/OASIS	Jet Propulsion Laboratory (JPL), USA
MSOP	National Aerospace Laboratory, Japan
OMNIS	Naval Surface Warfare Center, (NSWC), USA
PAGE3	National Geodetic Survey (NGS), USA
TEXGAP/MSODP	University of Texas Center for Space Research, (UTCSR), USA

Source:

IGN/ENSG/LAREG France

One Global Datum: the CTRS

CTRS = Conventional Terrestrial Reference System

How to get to the CTRS?

Through an Organization	With a given Name	As a list of Coordinates
IERS	ITRS	ITRF2000
DoD NIMA	WGS 84	WGS 84 (G873)
NGS	NAD 83	NAD 83 (CORS96)

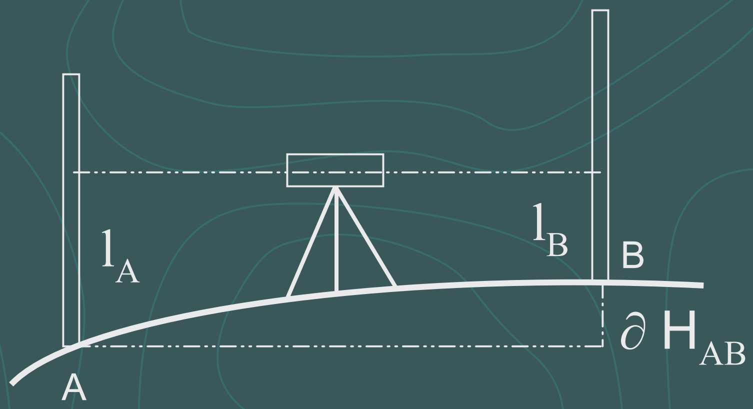
Solution for the Surface Network: Work within a realization of ITRS

- By using postfit GPS orbits expressed in ITRS coordinates. These are freely distributed by the International GPS Service (IGS).
- By transforming any other control points into the same reference frame.

GPS and GLONASS

	GPS	GLONASS
Managed by	US DoD	Russian Federation
Number of Satellites	24	24
Orbit Planes	6	3
Orbit Inclination in degree	55	64.8
Orbit Height in km	20200	19100
Carrier Frequency in MHz	L1: 1575.42 L2: 1227.60	L1: 1602 + n*0.5625 L2: 1246 + n*0.4375

Now, what about adding leveling observations?



Spirit Leveling

$$\partial H_{AB} = l_A - l_B$$

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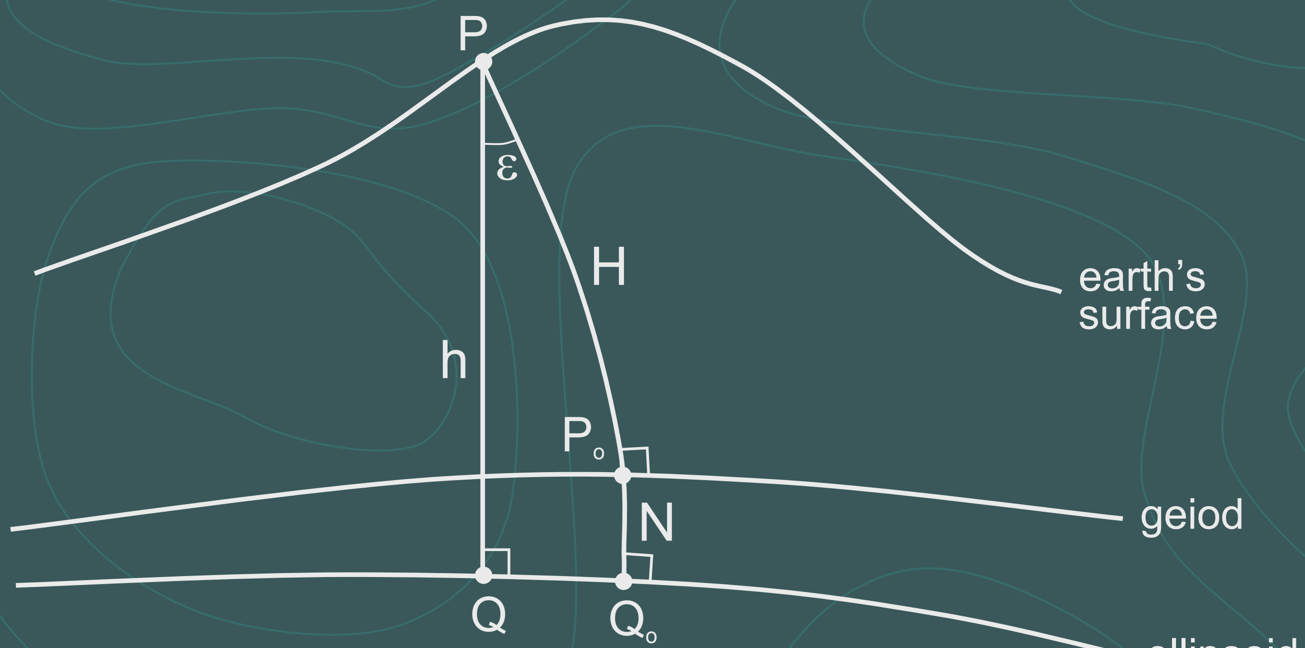
Different Height Systems

$$\int_{O}^{M} g\, dn = W_{O} - W_{M} = C_{M}$$

Dynamic	Normal	Orthometric
$Hdyn_{M} = \frac{C_{M}}{\gamma_{O}}$	$Hnor_{M} = \frac{C_{M}}{\bar{\gamma}}$	$Hort_{M} = \frac{C_{M}}{\bar{g}}$

With g measured (Earth) gravity, γ normal (Model) gravity

Pizzetti's Projection



How to compute geoid undulations?

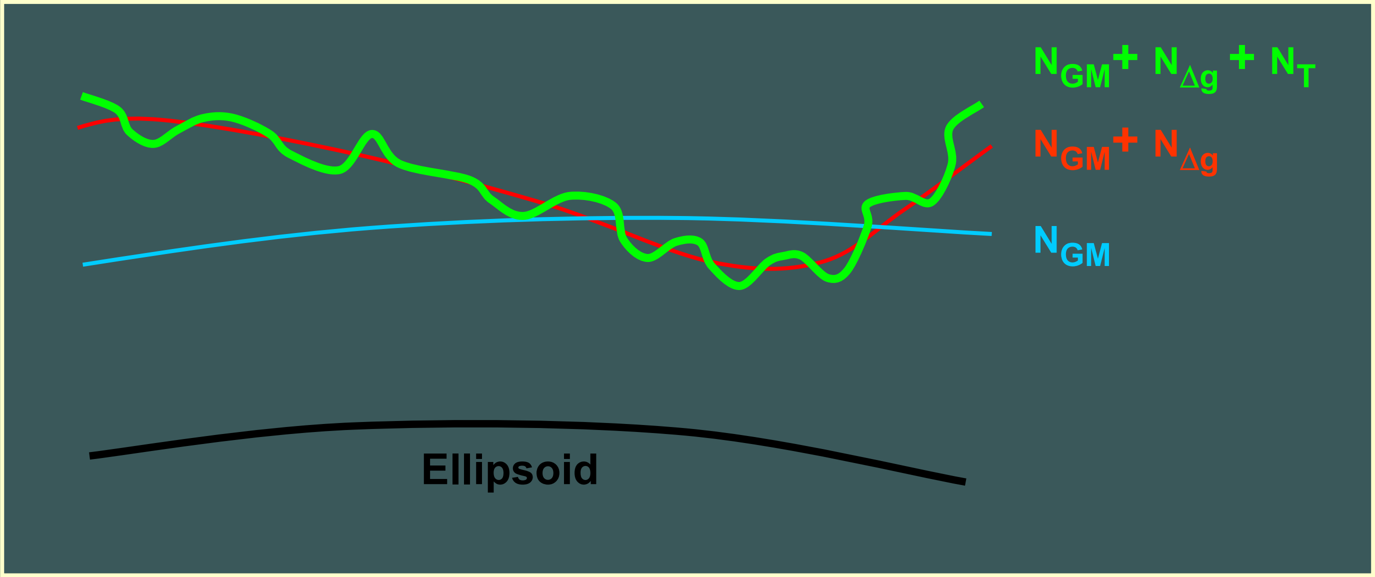
1. Directly $\mathrm{N} = \mathrm{h} + \mathrm{H}$

2. Bruns $\mathrm{N} = \dfrac{\mathrm{T}}{\gamma} = \dfrac{\mathrm{W\text{-}U}}{\gamma}$

3. Stokes $\mathrm{N} = \dfrac{\mathrm{R}}{4\pi\gamma} \iint_{\sigma} \Delta g \, S(\psi) \, d\sigma$

4. Helmert $d\mathrm{N} = -\varepsilon \, ds \quad \varepsilon = \xi \cos\alpha + \eta \sin\alpha$

Three components in the geoid



N_{GM} = long wavelength calculated from a geopotential model

$N_{\Delta g}$ = medium wavelength computed with Stokes

N_T = terrain correction

Local Geoid

- Start with a good regional geoid.

  In the US: G99SS published by NGS as a 1 by 1 arc minute grid.

- Add gravity measurements and generate finer terrain model.

- Incorporate geoid heights derived from GPS / leveling data.

What about tidal effects?

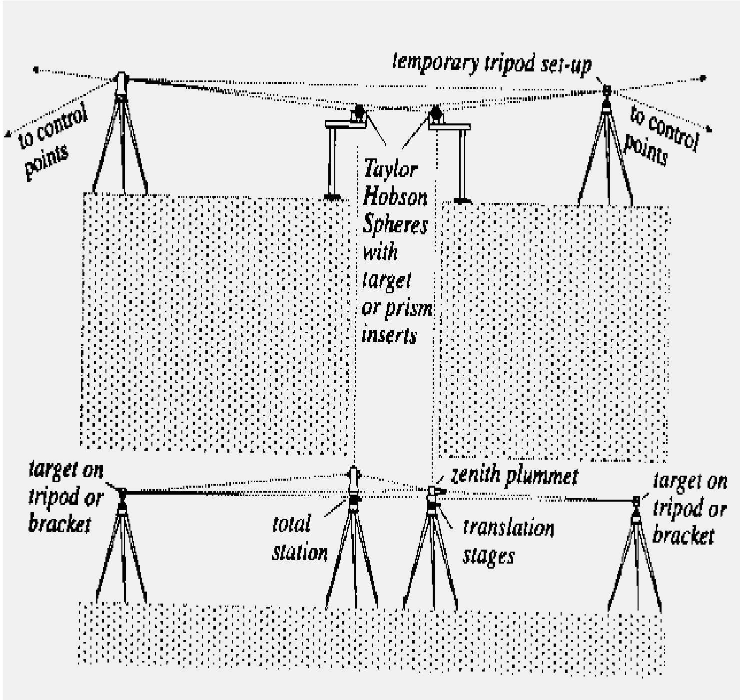
- **Tide-free**: All effects of the sun and moon removed.
- **Zero**: The permanent direct effects of the sun and moon are removed but the indirect component related to the elastic deformation of the earth is retained.
- **Mean**: No permanent tidal effects are removed.

Conventional Alignment
Transfer between Surface and Tunnel Networks

The datum of the surface network is transferred into the tunnel through penetrations or shafts.

Equipment:

Optical Plummet, EDM, Level



Plummet

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Conventional Alignment
Tunnel Network

Purpose:

Establishing a network of combined wall and floor monuments to be used in the placement and monitoring of the components .

Instruments Used:

- Theodolites, EDMs, Laser Trackers, Total Stations
- Levels
- Gyro-theodolites

Theodolites: TC2002 and T3000

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ME5000 EDM

Gyro-theodolite: GYROMAT 2000

Conventional Alignment

Components Alignment

Purpose:

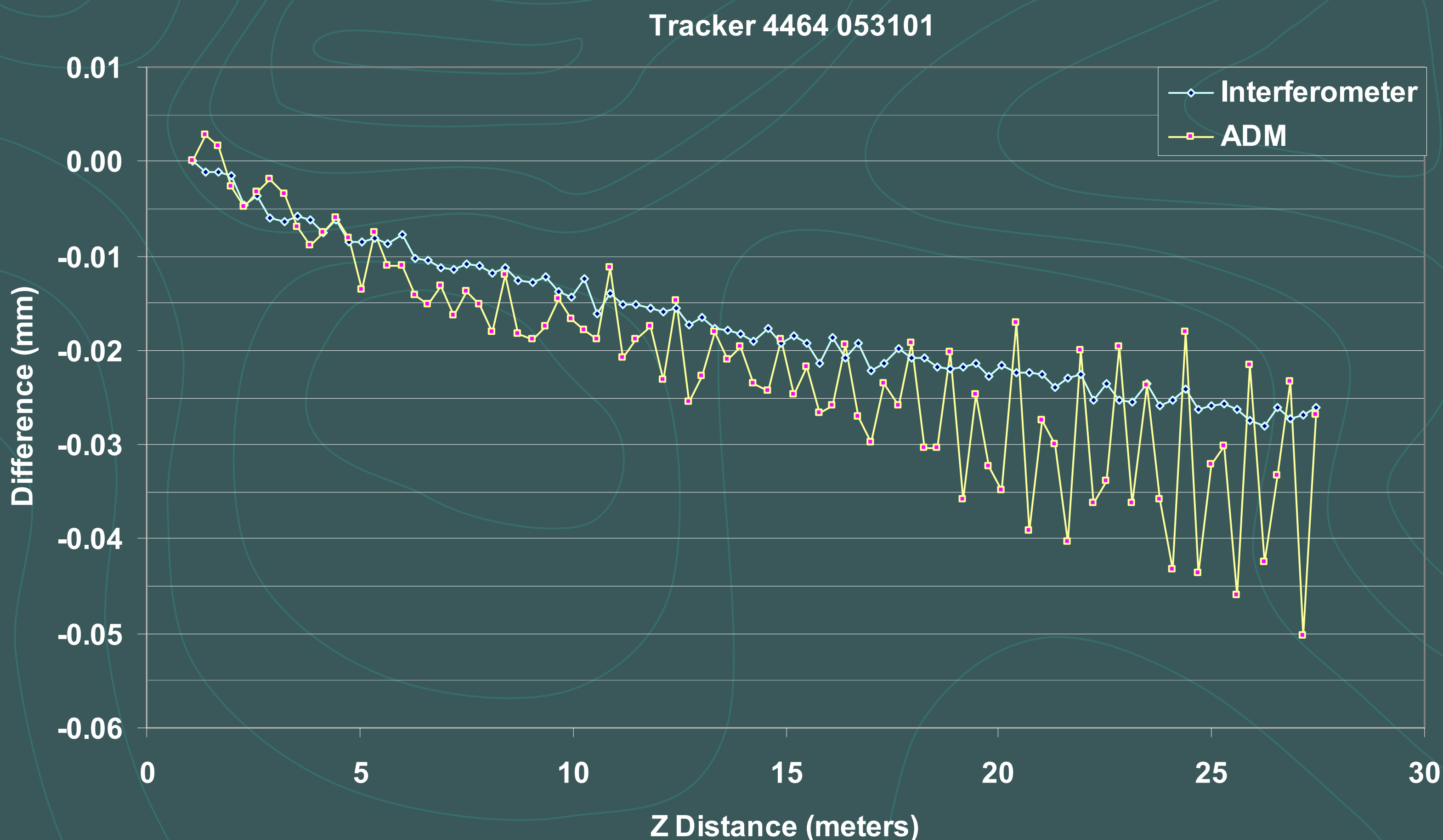
Laying out, installing, mapping and monitoring the accelerator components both locally and globally to the given tolerances.

Instruments Used:

- Total Stations
- Laser trackers + Levels

SMX Laser Tracker

Tracker vs. HP Interferometer



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Coordinate Systems

Machine Lattice – Site System: $\mathbf{X}^{S}$

1. Assign location: $\mathbf{X}_{O}^{C}$ or $(\lambda_{O}, \varphi_{O}, h_{O})$

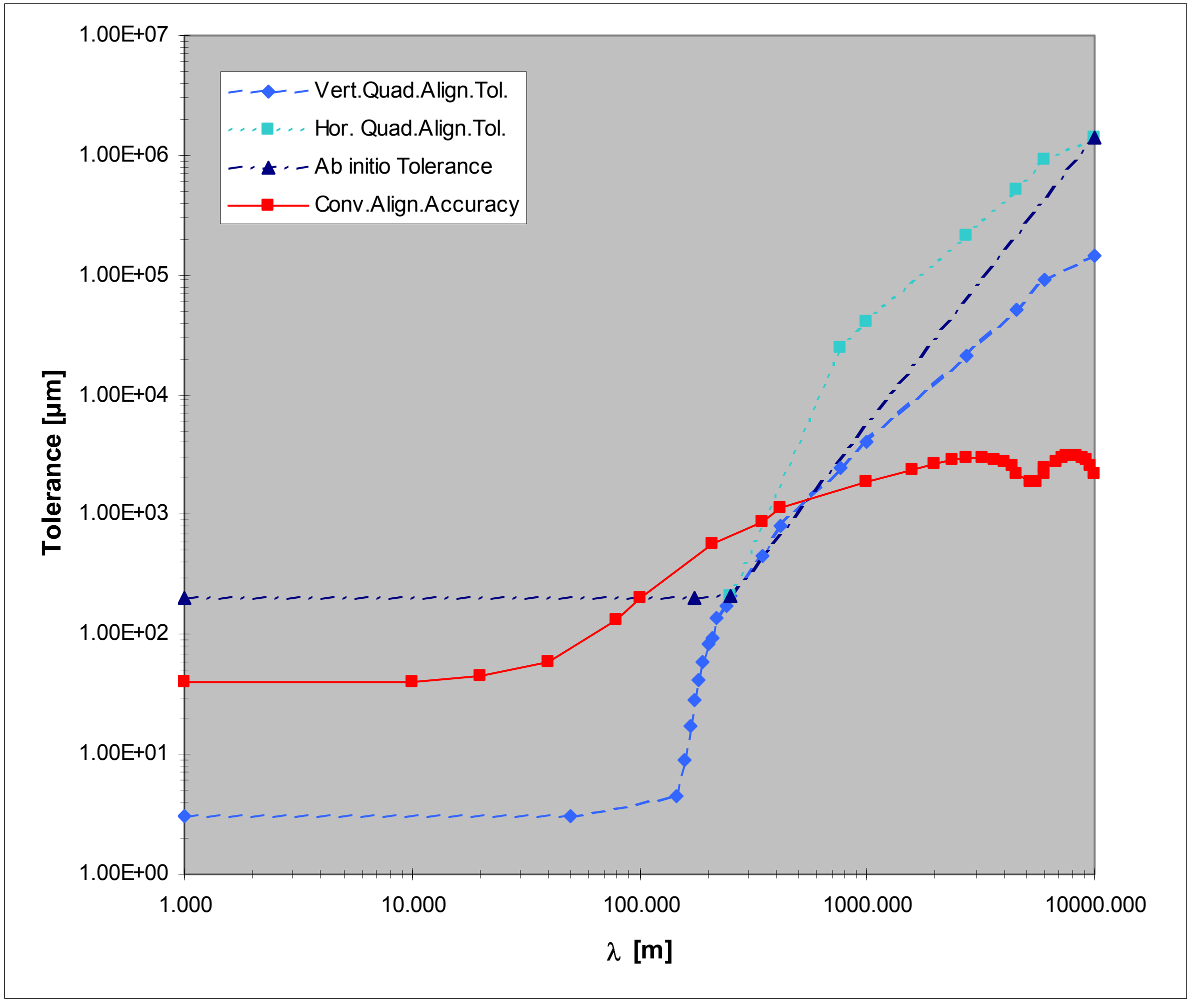
2. Choose orientation: $(\alpha, \mathrm{dip}=\mathrm{d}, \mathrm{strike}=\mathrm{s})$

Surface Network – Global System: $\mathbf{X}^{C}$

$$\boxed{\mathbf{X}^{C} = \mathbf{X}_{O}^{C} + R_{3}(\lambda_{O})R_{2}(\frac{\pi}{2} - \varphi_{O})R_{3}(\alpha)R_{2}(d)R_{3}(s)\,\mathbf{X}^{S}}$$

Conventional alignment capabilities vs. NLC linac alignment requirements

Conventional Alignment cannot meet NLC main linac short wavelength quadrupole tolerance requirements



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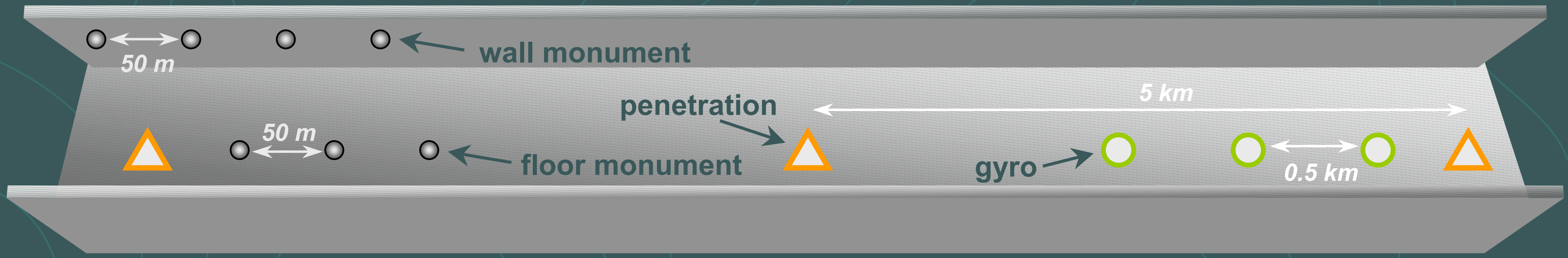
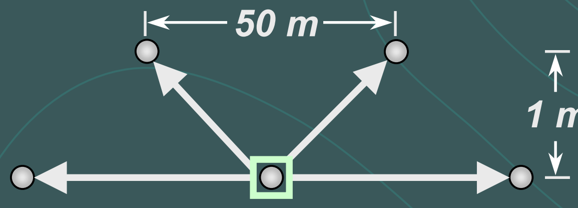
Simulated Layout



Old forced centering approach using 2D connected network approach:

- Horizontal angles .3 mgon
- Distances 100 μm
- Azimuths .5 mgon



Special Alignment Systems
Wire Systems

SLAC/DESY
- operational range: ± 1 mm
- resolution 100 nm
- bi-axial

KEK
- operational range: ± 2.5 mm
- resolution 2.5 µm
- Single axis

CERN
- operational range: ± 2.5 mm
- resolution 1 µm
- Single or two axis

Special Alignment Systems

Hydrostatic Level Systems

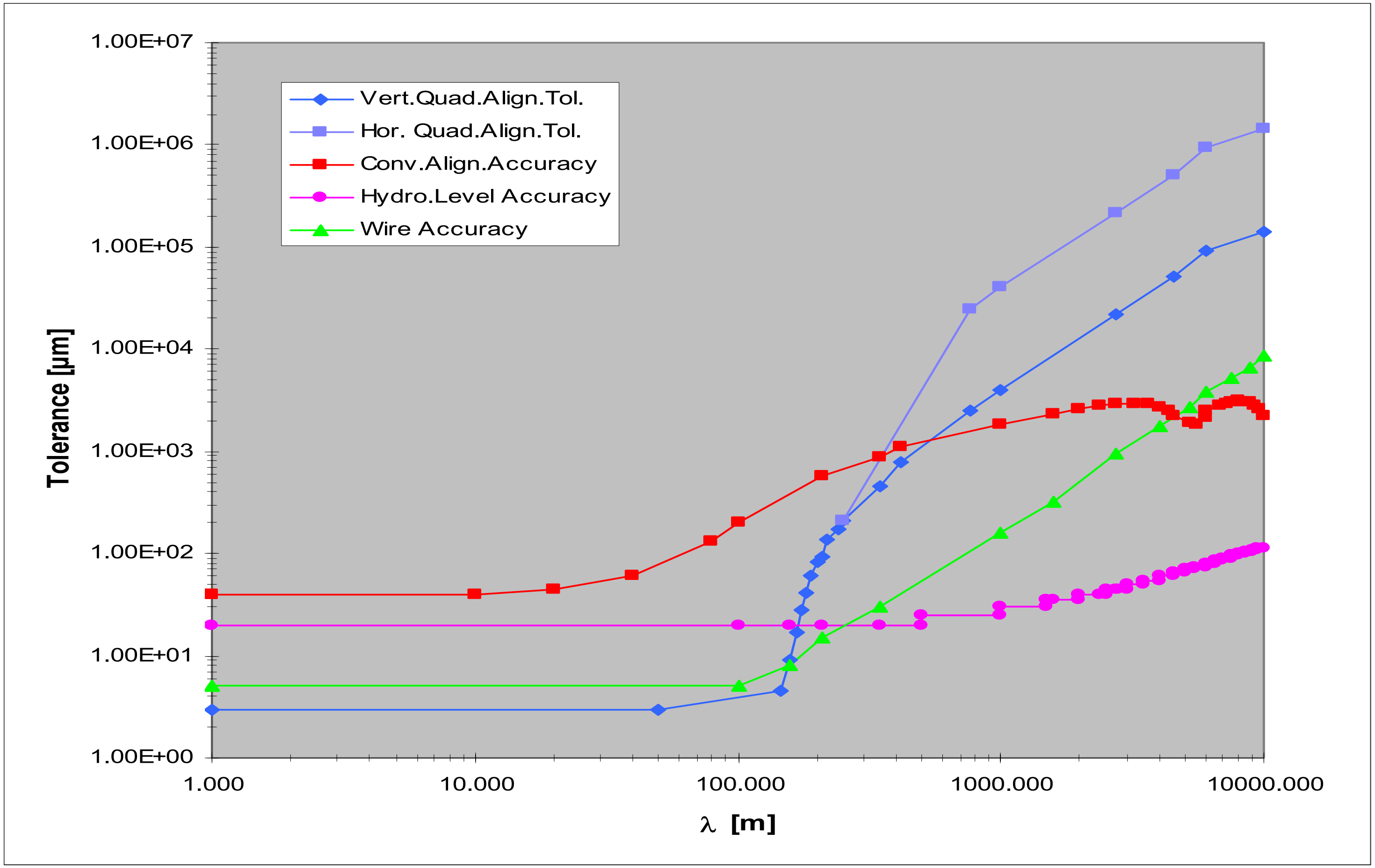
ESRF/Fogale Nanotech HLS

- water
- fully automated, tested
- res. 1µm, acc. ± 10 µm

SLAC FFTB System

- mercury based
- capacitive
- res. 0.5µm, acc. ±2 µm
- prototype

Conventional Alignment + Wire + HSL
vs.
NLC linac alignment requirements



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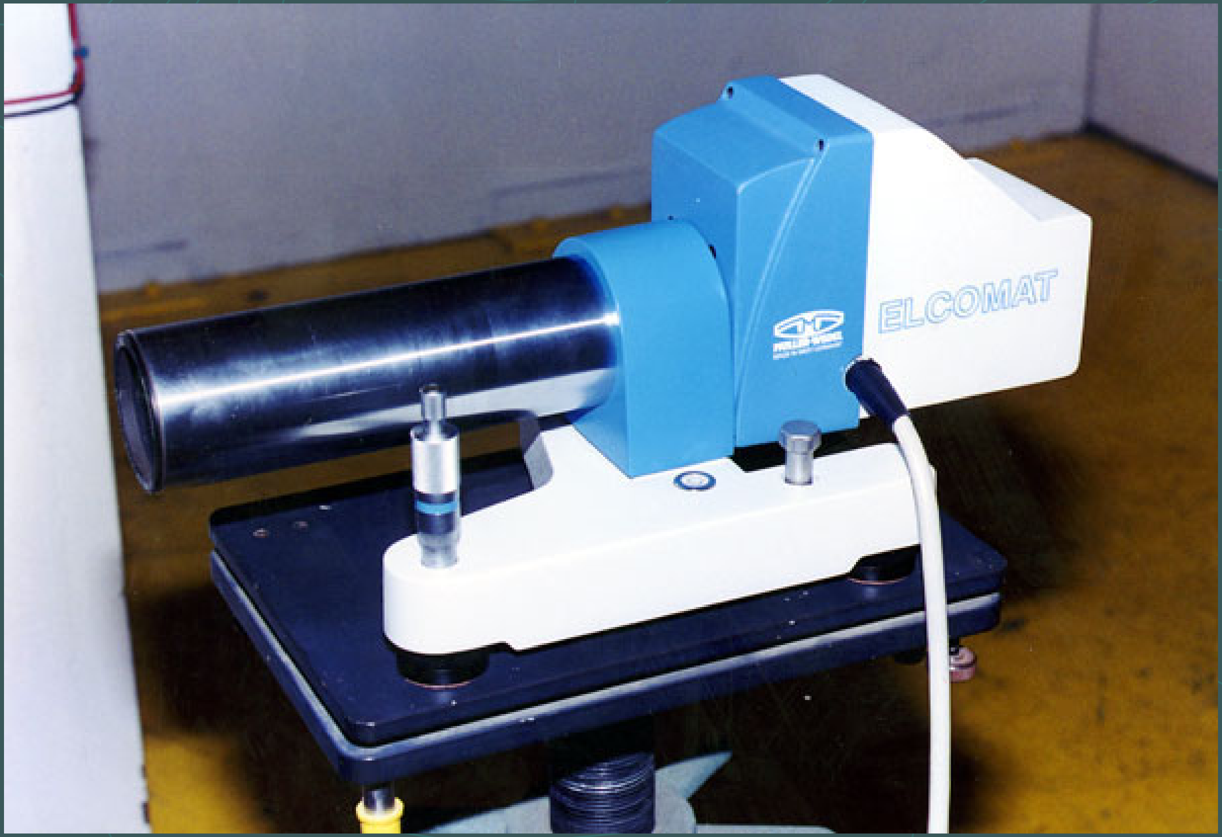
Special Alignment Systems

Straightness System with Movable Target

- Autocollimation (optical / electro-optical)
  - Taylor Hobson, DA 400
  - Möller-Wedel Elcomat 2000, ±5 µm/10 m
- Interferometric Measurements
  - HP, Zygo, ±5 µm/10 m
- Light Intensity Comparison
  - LMS200, ±10 µm/10m
- Fixed Beam, movable detector
  - Positioning System LRP, ±10 µm/10m

Autocollimation



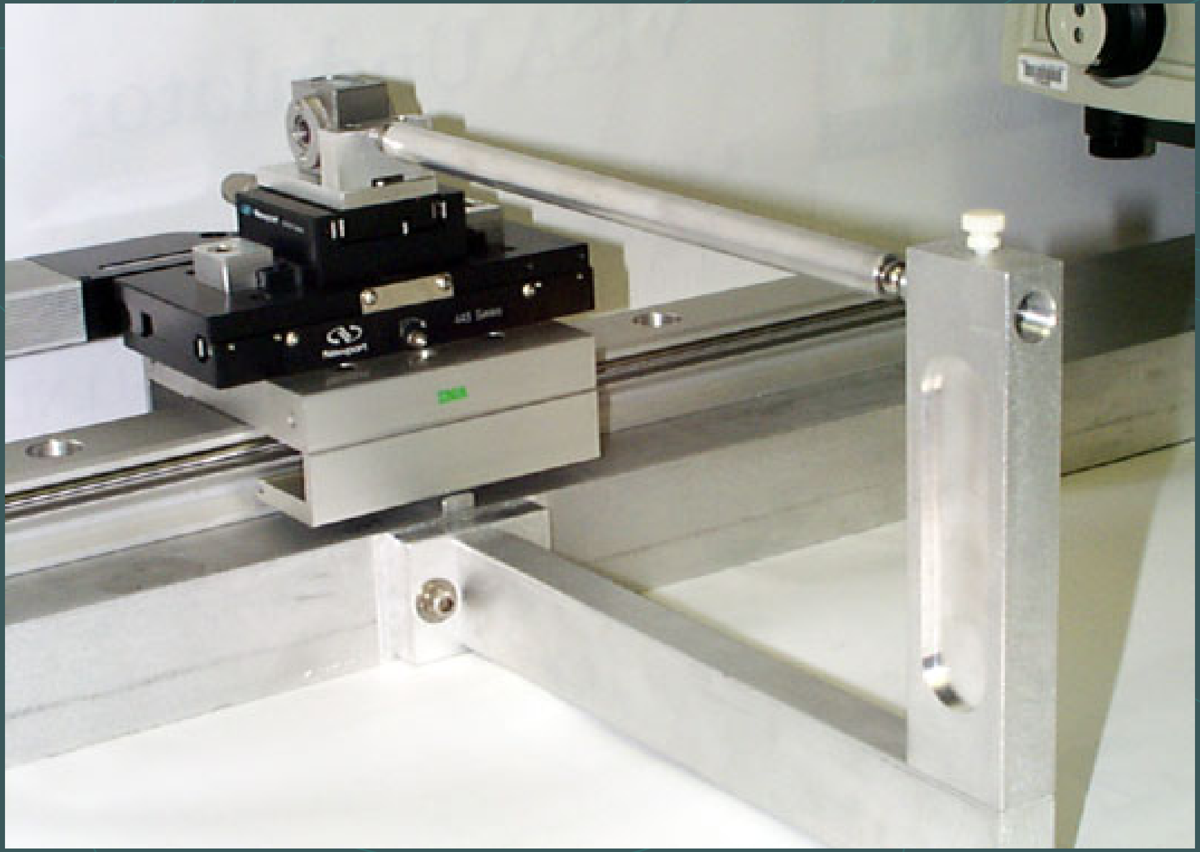
ELCOMAT 2000

Resolution 0.05”

Accuracy +/- 0.25”

Maximum Distance 25m

Interferometric Measurement



Special Alignment Systems

Straightness Systems with Stationary Target

Fixed Beam/fxd. Detector Laser System

- Retractable target (CERN, *Quesnel*), ±20 µm/50 m
- Fixed transparent target (Max-Plank-Institute/CERN, Munich), max. 6 targets, ±50 µm/50 m

Diffraction Optics System

- Fresnel Lens (SLAC), ±50 µm/3000 m
- Poisson Sphere (LNL, *Griffith*), ±5 µm/50 m

RTRSS

Rapid Tunnel Reference Survey System

TESLA Alignment Working Group

chaired by J. Prenting, DESY

W. Schwarz, Weimar University

R. Ruland, SLAC

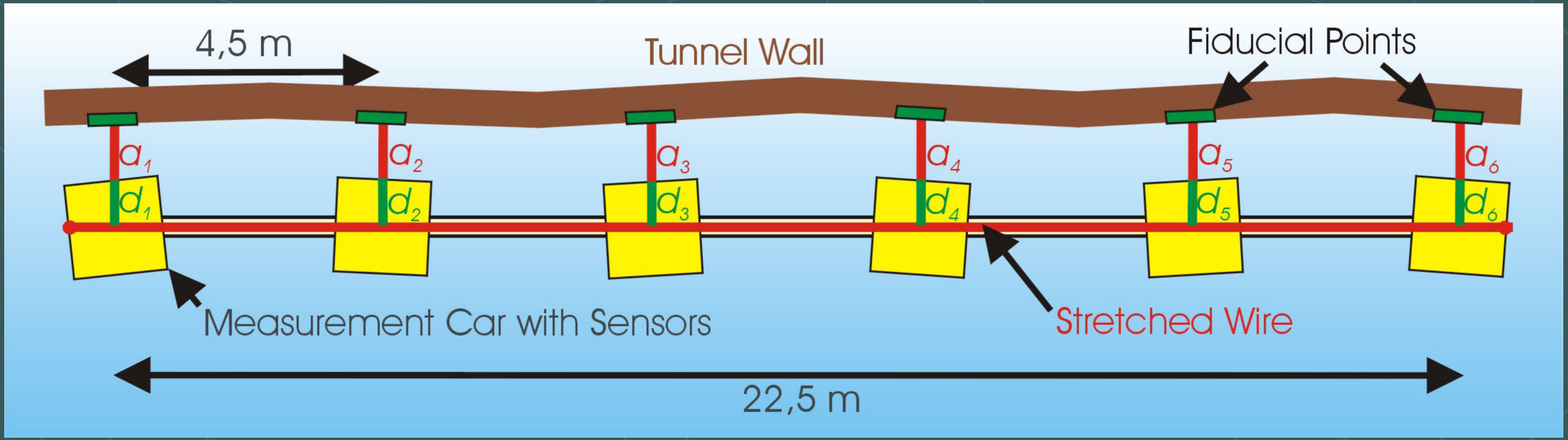
RTRSS

Development Stages

- Initial Investigation
  - FFTB stretched wire
- First Concept
  - Rigid 5 m long bar
- Actual Design
  - Train 22.5 m long with 6 measurement cars

RTRSS

Measurement Train



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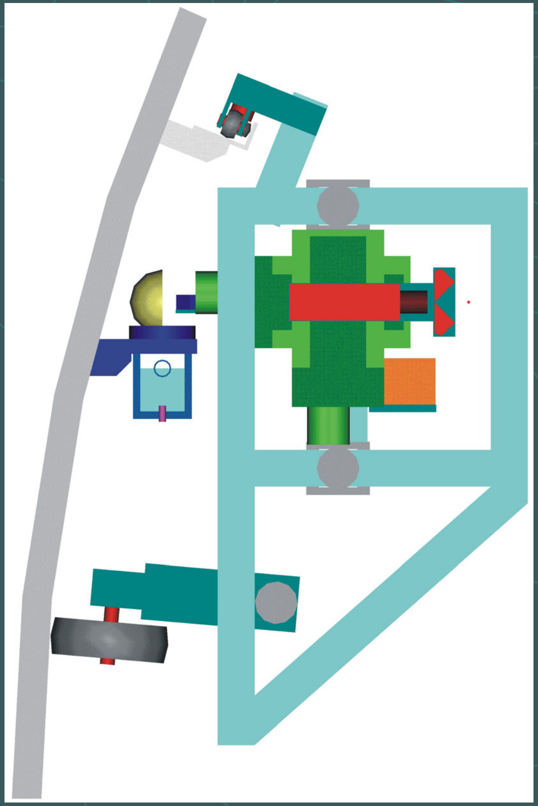
RTRSS

Individual Measurement Car



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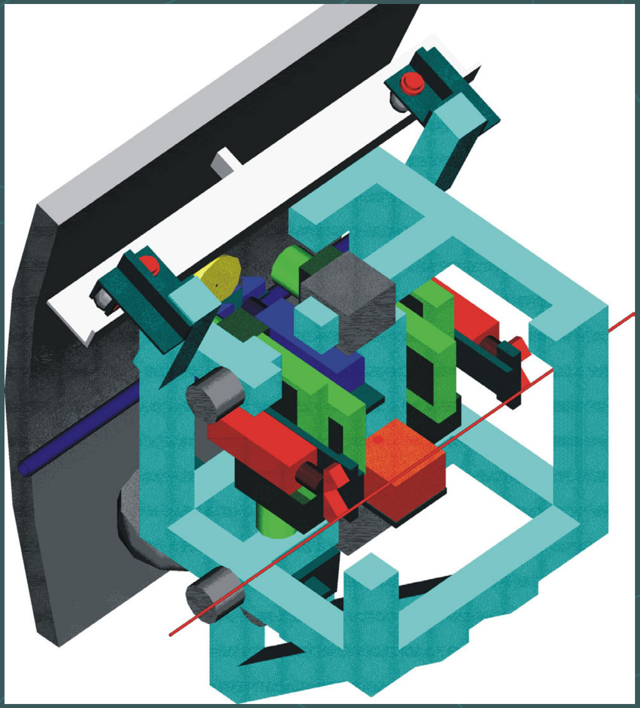

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Proposed Strategy

Surface Network	▸	GPS + Levels
Transfer Network	▸	Plummet, wire, etc
Tunnel Network	▸	RTRSS
Components Placement	▸	Laser Trackers

Present and Future Studies

- Instrumentation
  - RTRSS development at DESY
- Modeling
  - Micro geoid
  - Adjustment simulation
- Information System
  - GIS